# NASA Technical Memorandum 102737

## Effect of Shaping Sensor Data on Pilot Response

Roger M. Bailey

November 1990

(NASA-TM-102737) EFFECT OF SHAPING SENSOR DATA ON PILOT RESPONSE (NASA) 19 p CSCL 01D N91-15173

Unclas
G3/06 0326559

National Aeronautics and
Space Administration

**Langley Research Center**
Hampton, Virginia 23665-5225

## SUMMARY

The pilot of a modern jet aircraft is subjected to varying workloads while being responsible for multiple, ongoing tasks. The ability to associate the pilot's responses with the task/situation, by modifying the way information is presented relative to the task, could provide a means of reducing workload. To examine the feasibility of this concept, a real-time simulation study was undertaken to determine whether preprocessing of sensor data would affect pilot response. Results indicated that preprocessing could be an effective way to tailor the pilot's response to displayed data. In this study, the effects of three transformations or "shaping functions" were evaluated with respect to the pilot's ability to predict and detect out-of-tolerance conditions while monitoring an electronic engine display. In this experiment, two non-linear transformations, one being the inverse of the other, were compared to a linear transformation. Results indicate that a non-linear transformation that increases the rate-of change of output relative to input tends to advance the prediction response and improve the detection response, while a non-linear transformation that decreases the rate-of-change of output relative to input tends to lengthen the prediction response and make detection more difficult.

## INTRODUCTION

Information management is one of the most important issues confronting the designers of modern cockpits today. Although there have been remarkable advancements made in many areas of information technology (how information is processed, integrated, transmitted, displayed, and ultimately used), the majority of the work has focused on hardware and software, rather than human factors. Advancements in computers, digital processing, sensor technology, and electronic displays can provide vast amounts of information to the pilot. The critical aspect of information management has now become the interface between the information source and the human element in the system. The essence of effective decision making is good information, properly condensed and displayed in a way that allows it to be assimilated in the time available. Information is now available, in overwhelming quantity. We now have the task of processing and displaying it in such a way that it becomes a better tool for decision making in the cockpit.

In current cockpits, engine data is typically presented to the pilot via some type of electromechanical display device or an electronic device (typically a cathode ray tube or CRT) with electromechanical representations. These gauges and indicators generally portray the information from the various engine sensors directly. Consequently, sensor data is presented the same way, linearly (i.e., output to display device is equal to the input from sensor), at all times. Assuming that the form of the data has an effect on the pilot's response, there may be instances where a presentation mechanization other than linear would be desirable. For example, during an approach-to-landing under adverse weather conditions, the pilot is burdened with a heavy workload and may not notice an engine problem developing. With a non-linear shaping function, the information display representing the developing engine problem could be enhanced in order to attract the pilots attention, thus averting a potentially dangerous situation.

A non-linear transformation or "shaping function" could be used to reduce pilot response time under appropriate conditions or provide for more accurate determination of out-of-tolerance conditions. A part-task, real-time simulation study was devised to determine the effect, on the pilot's response, of shaping the sensor data in a non-linear manner.

## DESCRIPTION OF SIMULATION

This study utilized a fixed-base simulator configured as the research cockpit of the NASA Transport Systems Research Vehicle (TSRV) airplane (ref. 1-2). Also utilized was a JT8D-7 simulation engine model for B-737 aircraft, which had been modified for dynamic response and engine limits. Although the 737 is a two-engine aircraft, this experiment was designed and the displays configured for a single engine. The research cockpit (fig. 1) was configured with six, 9-inch diagonal color display units. Electronic primary and navigation displays were provided on the two CRT units directly in front of the pilot (left side of the cockpit). The electronic display for engine monitoring was provided on the left center-mounted CRT. The formats for these displays were generated on an Adage AGT 340 graphics computer.

An electronic display format for engine monitoring (ref. 3) was developed for this study (fig. 2) which incorporated bar deviation indicators for the following seven (7) engine parameters: compressor fan speed - stage 1 (N1), compressor fan speed - stage 2 (N2), exhaust gas temperature (EGT), fuel flow (FF), oil temperature (OT), oil pressure (OP) and oil quantity (OQ). The display indicated the basic operating regions for the engine parameters: normal, caution (high), and warning (high). Additionally, the oil system parameters required indicators for caution (low), and warning (low). The boundary for each region was indicated by a colored, horizontal line: green for normal, yellow for caution, and red for warning. The deviation bars were white.

## ENGINE DATA SHAPING ALGORITHMS

Since the purpose of this study was to determine whether preprocessing sensor data would affect pilot response, the manner in which the sensor data was processed was one major consideration. In this study, a set of three mathematical transformations, referred to as "shaping functions", were used to modify the engine sensor data before it was displayed: a linear function (output=input) was used as a baseline for comparison (fig. 3), and two non-linear functions were used, with each exhibiting different characteristics, especially around the transition boundaries between the normal, caution, and warning regions. The first non-linear function was referred to as the "Fast Transition" function (fig. 4), and was characterized by larger changes in output data relative to changes in input data (underdamping) as the boundary thresholds were approached. The second non-linear function was referred to as the "Slow Transition" function (fig. 5). This Slow Transition function was the inverse of the Fast Transition function. As Figure 5 indicates, this function was characterized by smaller changes (overdamping) in output data relative to changes in input data as the boundary thresholds were approached. The characteristic equations for these shaping functions are given in Appendix A.

## EXPERIMENT DESCRIPTION

In this experiment, the subject's task was to monitor the center-panel engine display. The simulator was operated with the auto-pilot and auto-throttle engaged, therefore, the subjects were not required to pilot the simulator. Although the simulation was conducted in auto-pilot mode, the pilot was required to use two switches on the left-hand-mounted side-stick controller; a trigger switch and a thumb switch. When either switch was engaged, a digital timer and data recorder were simultaneously activated to record pilot-response timing data.

Each trial began with all engine parameters within normal operating limits. In this experiment, three of the seven engine parameters (N2, EGT, and OP) were selected to proceed out-of-tolerance or fail (i.e., go from normal operating limits into caution or warning regions). Each trial was designed to last approximately 1 minute. At some point, 15-25 sec. after the start of each trial, one of the three selected engine parameters would proceed out-of-tolerance. Only one of the three selected parameters would fail during a trial. Once the subject determined that a parameter was proceeding out-of-tolerance, the monitoring task was then divided into two phases: a prediction phase and a detection phase. In the prediction phase, the subject was required to estimate when a boundary transition (normal-to-caution or caution-to-warning) was 1 sec. from occurring. At this time, the trigger switch on the side-stick would be pressed. For example, as the deviation bar representing the failing engine parameter moved from the normal operating area toward the caution area, the subject would estimate when the leading edge of the bar was 1 sec. away from traversing the yellow normal-caution boundary line. At that time, he would press the trigger switch on the side-stick. In the detection phase, the subject was required to determine when a boundary transition actually did occur. At that time, he would press the thumb switch on the side-stick. Continuing with the previous example, after completing the prediction phase, the subject had to continue monitoring the engine display. The thumb switch on the side-stick would be pressed when the leading edge of the deviation bar appeared to traverse the yellow boundary line. A short questionnaire was completed by the test subject after each trial (see Appendix B).

Prior to this experiment, a preliminary evaluation of the experimental methodology was completed. In this preliminary evaluation, the task was the same as that described previously; however, based on the results of the preliminary evaluation, there were significant differences in implementation between the preliminary evaluation and the actual experiment. These changes, and the reasons behind them, will be discussed in the following paragraphs.

First of all, for the preliminary evaluation, each subject was given an unlimited number of practice trials during which each of the shaping functions were implemented with a failure scenario (a preprogrammed system malfunction, whereby an engine parameter proceeds from in-tolerance to out-of-tolerance). Once the subject expressed confidence in his ability to distinguish between the effects of the different shaping functions, a short test was administered which required correct identification of all three shaping functions. After reviewing pilot comments, and the notes taken during the preliminary evaluation, it appeared that the subjects decided which shaping function they preferred during the practice session, then "looked" for that shaping

function during the experimental trials. Consequently, timing data was suspect because the subjects were busy trying to guess which shaping function was being implemented instead of attending to the required task, i.e., predicting and detecting boundary transitions. In an attempt to prevent these bias effects in the actual study, subjects were not given any practice trials.

The second major change prompted by the preliminary evaluation involved the test matrix. In the preliminary evaluation, in order that every possible combination of the three shaping functions with three failure scenarios could be evaluated, each subject completed nine data runs in the simulator. Upon reviewing the results, it was determined that even though all combinations of failures and shaping functions were presented to each subject, a more effective comparison of the shaping transformations would involve a means of making sure that, if taken in pairs, each shaping function was presented after each of the other two. Consequently, in the actual experiment, not only was every possible combination of the three shaping functions with three failure scenarios compared, but all three shaping functions were sequentially compared to each other. This was achieved by presenting each subject with every possible dual sequence of shapers (e.g., linear baseline, then linear baseline; linear baseline, then fast transition; linear baseline, then slow transition; fast transition, then linear baseline, etc.). Consequently, each subject completed 20 data runs in the simulator, with the presentation order for each shaper-failure combination being randomized for each subject. The test matrix for the preliminary evaluation is given in Table 1, and the test matrix for the actual experiment is given in Table 2. Three NASA test pilots participated as subjects in the preliminary evaluation. The actual study also utilized three NASA test pilots as subjects, one of whom participated as a subject in the preliminary evaluation.

The third change prompted by the preliminary evaluation involved the manner in which the simulated engine sensor data was mapped onto the different operating regions (normal, caution, and warning) of the display. More specifically, changes were made in that section of the failure algorithm devised to control the rate of change of the selected engine system parameter. During a failure, the changes in the affected engine parameter were generated by a set of simple linear equations of the form: output = [slope x duration of failure(sec.)] + constant , where the slope governed the rate at which the engine parameter would change. In the preliminary evaluation, separate failure equations, each with a different slope, were used for each region of operation on the display. Upon analysis of the results, this multiple variation in slope was determined to be unnecessary and imprudent. The non-linear shaping functions altered the rate of change of the deviation bars, with emphasis being placed on transition boundaries. The use of different slopes for each region of the display produced an additional alteration to the deviation bars' rate of change, at operating region transition boundaries. As a result, it was difficult to determine what effect the shaping function alone had on pilot response. Therefore, in the actual experiment, one equation was used to generate each failure scenario, with a single slope governing the rate at which an engine parameter would change, regardless of the operating region.

## DATA ANALYSIS

Both qualitative and quantitative data were taken during this experiment. Qualitative data were in the form of subject responses to short questionnaires presented after each trial (see Appendix B). Quantitative data were in the form of timing measurements based on the two switches on the side-arm controller. An analysis of variance technique and the Student-Neuman Keuls' test (ref. 4) were used to evaluate the quantitative data. Statistical results were deemed significant at the 95-percent confidence level. The Linear function was used as a reference for this analysis. This reference choice was made for two reasons. First, the constant slope, which is characteristic of the linear function, provides a good reference of comparison for any non-linear function. Second, the linear format (output = input) is the presentation mechanism typically found in the cockpit today.

## RESULTS AND DISCUSSION

Although the statistical analysis of the quantitative data indicated that the differences in mean prediction and mean errors for detection were not significant at the 95-percent confidence level, the data did reveal some interesting response trends as a function of the fast transition shaper and the slow transition shaper.

Examination of the pilot timing measurements indicated that, during the prediction phase of the task, the Fast Transition function and the Slow Transition function elicited opposite responses. Figure 6 shows that the Slow Transition function produced an early prediction response (i.e., trigger switch pressed at some time before the 1.0 sec. prediction threshold). Conversely, the Fast Transition function elicited a late response. The important result is that, compared to the Linear Baseline function, both non-linear transformations produced noticeably divergent reactions.

For the detection task, pilot timing data indicated the Fast Transition function enhanced the pilots response, while the linear and slow transition functions degraded pilot response. Figure 7 shows that the Fast Transition function produced a more accurate detection response than either the Slow Transition function, which produced the least accurate detection response, or the Linear Baseline function. The decreasing rate of change, could have prompted the test subjects to make a premature detection response, resulting in the increased mean error times.

From the results and discussion presented above, it can be seen that the non-linear transformations have an effect on pilot response. Quantitative results indicate that a non-linear transformation, which increases the rate-of-change of output relative to input, advances the prediction response and improves the detection response. A non-linear transformation, which decreases the rate-of-change of output relative to input, lengthens the prediction response and makes detection more difficult. The overall qualitative results support the subjects' quantitative responses. The qualitative results suggest that the subjects did not find the Slow Transition function helpful. Within the Slow Transition function, the non-linear transformations are characterized by smaller changes (overdamping) in output data relative to changes in input data as the boundary thresholds are approached. Questionnaire responses indicated the subjects objected to the decreased resolution at the transition boundaries, caused by this

overdamping. In general, the subjects considered the Fast Transition function to be better for the monitoring task; especially during the detection phase. Since the Fast Transition function exaggerates changes in the input signal as the boundary is approached, the increased resolution near the boundary provides better cues that a change of state is about to occur and aids in the detection of a transition.

## CONCLUSIONS

A real-time simulation study was conducted to determine the effect on subject performance of two different non-linear transformations or shaping functions used to modify engine sensor data prior to display. Based on the quantitative and qualitative results, the following conclusions are drawn:

1. Shaping functions provide a practical means for affecting subject response.

2. A function, with characteristics of the Slow Transition function, that decreases resolution around transition boundaries may be effective in situations requiring earlier prediction.

3. A function, with characteristics of the Fast Transition function, that increases resolution around transition boundaries is effective in situations requiring rapid detection.

4. Preprocessing of sensor data could be an effective way to tailor the pilot's response to a particular task or situation.

# APPENDIX A

## EQUATIONS DESCRIBING THE SHAPING FUNCTIONS

The mathematical transformations used to generate the shaping functions are presented below. The non-linear transformations require a separate function for each operating area (i.e. normal - caution - warning).

Linear Baseline Function

$$y(x) = x$$

Fast Transition Function

$$y(x)_{\text{normal}} = h_1 \left( 1 - \cos \left[ \frac{\pi}{2} \left( \frac{x}{b_1} \right) \right] \right)$$

$$y(x)_{\text{caution}} = h_1 + h_2 \left( \frac{x - b_1}{b_2 - b_1} \right) + \frac{h_2}{8} \sin \left[ 2\pi \left( \frac{x - b_1}{b_2 - b_1} \right) \right]$$

$$y(x)_{\text{warning}} = h_1 + h_2 + h_3 \sin \left[ \frac{\pi}{2} \left( \frac{x - b_2}{b_3 - b_2} \right) \right]$$

Slow Transition Function

$$y(x)_{\text{normal}} = h_1 \sin\left[\frac{\pi}{2}\left(\frac{x}{b_1}\right)\right]$$

$$y(x)_{\text{caution}} = x - \frac{h_2}{8} \sin\left[\frac{\pi}{2}\left(\frac{x - b_1}{b_2 - b_1}\right)\right]$$

$$y(x)_{\text{warning}} = h_1 + h_2 + h_3 \sin\left[\frac{\pi}{2}\left(\frac{x - b_2}{b_3 - b_2}\right)\right]$$

# APPENDIX B

## SHORT QUESTIONNAIRE

(presented after each trial - preliminary evaluation and actual study)

1. Which shaping function was used:

   A] function 1 B] function 2 C] function 3 D] not sure

2. Was this shaping function different from the previous shaping function (disregard this question on first trial):

   A] yes B] not sure C] no

3. If answer for question 2 is "yes", was this shaping function better, compared to the previous shaping function, for predicting condition transitions:

   A] better B] the same C] worse

## REFERENCES


1. Reeder, J.P.; Schmitz, R.A.; and Clark, C.V.: Operational Benefits From the Terminal Configured Vehicle. NASA TM 80046, 1979.

2. Abbott, Terence S.; Nataupsky, Mark,; and Steinmetz, George G.: Effects of Combining Vertical and Horizontal Information Into a Primary Flight Display. NASA TP-2783, 1987.

3. Abbott, Terence S.: A Simulation Evaluation of the Engine Monitoring and Control System Display. NASA TP-2960, 1989.

4. Steele, Robert G.D.; and Tarrie James T.: *Principles and Procedures of Statistics.* McGraw Hill New York, 1960.

# TABLE 1. - Test Matrix for 3 subjects (preliminary evaluation)

| Pilot | Trial | Failure | Shaper |
|---|---|---|---|
| 1 | 1 | 1 | Linear |
| 1 | 2 | 2 | Fast |
| 1 | 3 | 3 | Slow |
| 1 | 4 | 1 | Slow |
| 1 | 5 | 2 | Linear |
| 1 | 6 | 3 | Fast |
| 1 | 7 | 1 | Fast |
| 1 | 8 | 2 | Slow |
| 1 | 9 | 3 | Linear |
| 2 | 1 | 2 | Fast |
| 2 | 2 | 3 | Slow |
| 2 | 3 | 1 | Slow |
| 2 | 4 | 2 | Linear |
| 2 | 5 | 3 | Fast |
| 2 | 6 | 1 | Fast |
| 2 | 7 | 2 | Slow |
| 2 | 8 | 3 | Linear |
| 2 | 9 | 1 | Fast |
| 3 | 1 | 3 | Slow |
| 3 | 2 | 1 | Slow |
| 3 | 3 | 2 | Linear |
| 3 | 4 | 3 | Fast |
| 3 | 5 | 1 | Fast |
| 3 | 6 | 2 | Slow |
| 3 | 7 | 3 | Linear |
| 3 | 8 | 1 | Fast |
| 3 | 9 | 2 | Slow |

## TABLE 2. - Test Matrix for 3 subjects (actual experiment)

### Pilot 1

| Trial | Failure | Shaper |
|---|---|---|
| 1 | 3 | Linear |
| 2 | 1 | Slow |
| 3 | 2 | Fast |
| 4 | 2 | Slow |
| 5 | 1 | Linear |
| 6 | 1 | Fast |
| 7 | 3 | Fast |
| 8 | 2 | Linear |
| 9 | 3 | Slow |
| 10 | 3 | Fast |
| 11 | 2 | Slow |
| 12 | 2 | Fast |
| 13 | 3 | Slow |
| 14 | 1 | Linear |
| 15 | 3 | Fast |
| 16 | 3 | Linear |
| 17 | 2 | Linear |
| 18 | 1 | Slow |
| 19 | 1 | Fast |
| 20 | 2 | Linear |

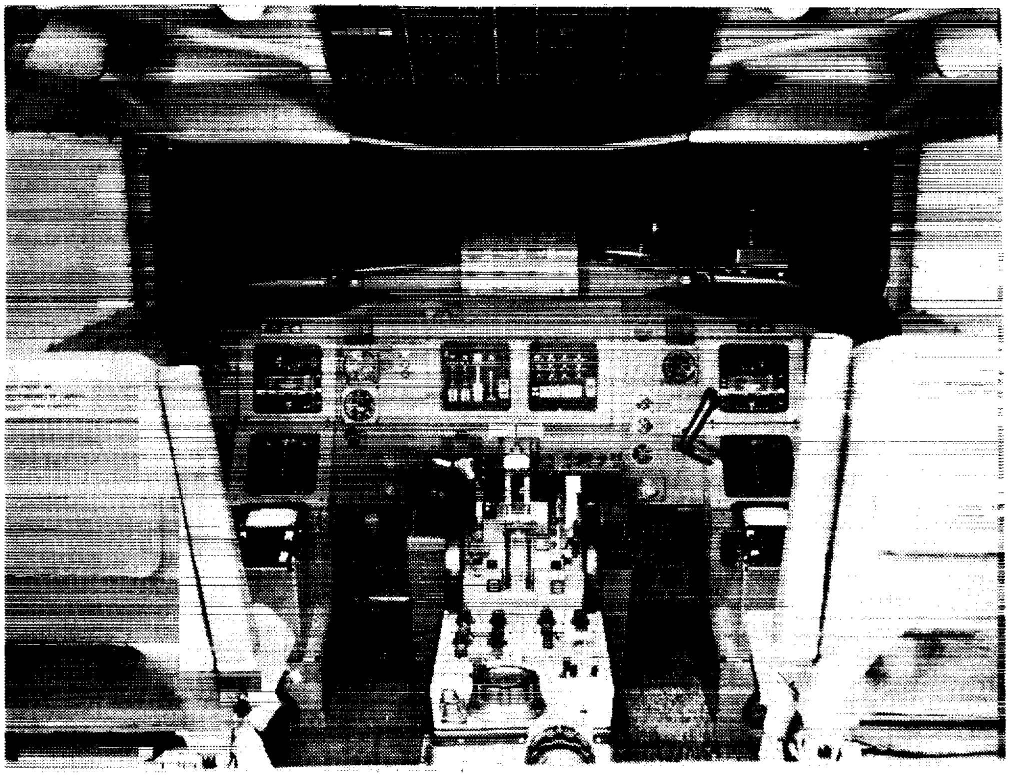
### Pilot 2

| Trial | Failure | Shaper |
|---|---|---|
| 1 | 1 | Fast |
| 2 | 3 | Linear |
| 3 | 2 | Linear |
| 4 | 3 | Slow |
| 5 | 3 | Fast |
| 6 | 1 | Slow |
| 7 | 2 | Slow |
| 8 | 2 | Fast |
| 9 | 1 | Slow |
| 10 | 1 | Linear |
| 11 | 1 | Fast |
| 12 | 2 | Fast |
| 13 | 3 | Slow |
| 14 | 3 | Linear |
| 15 | 1 | Slow |
| 16 | 3 | Fast |
| 17 | 2 | Linear |
| 18 | 2 | Slow |
| 19 | 1 | Linear |
| 20 | 1 | Fast |

### Pilot 3

| Trial | Failure | Shaper |
|---|---|---|
| 1 | 2 | Slow |
| 2 | 1 | Linear |
| 3 | 1 | Fast |
| 4 | 2 | Linear |
| 5 | 3 | Fast |
| 6 | 1 | Slow |
| 7 | 3 | Slow |
| 8 | 3 | Linear |
| 9 | 2 | Fast |
| 10 | 2 | Slow |
| 11 | 3 | Fast |
| 12 | 2 | Linear |
| 13 | 3 | Slow |
| 14 | 3 | Linear |
| 15 | 1 | Slow |
| 16 | 2 | Fast |
| 17 | 2 | Slow |
| 18 | 1 | Fast |
| 19 | 1 | Linear |
| 20 | 3 | Slow |

ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH



L-86-3593

**Figure 1. TSRV Cockpit Simulator**

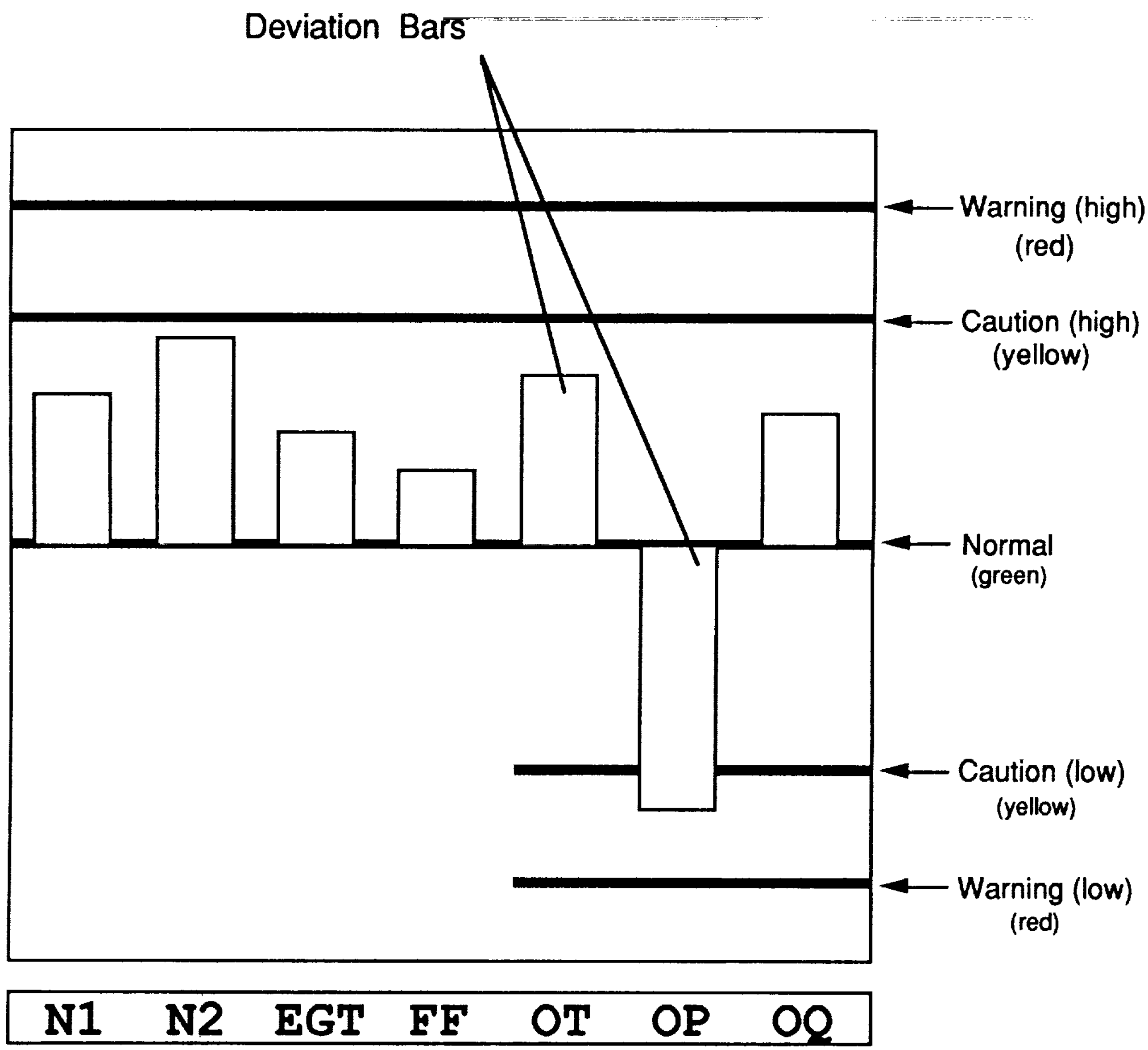



**Figure 2. - Engine display format**

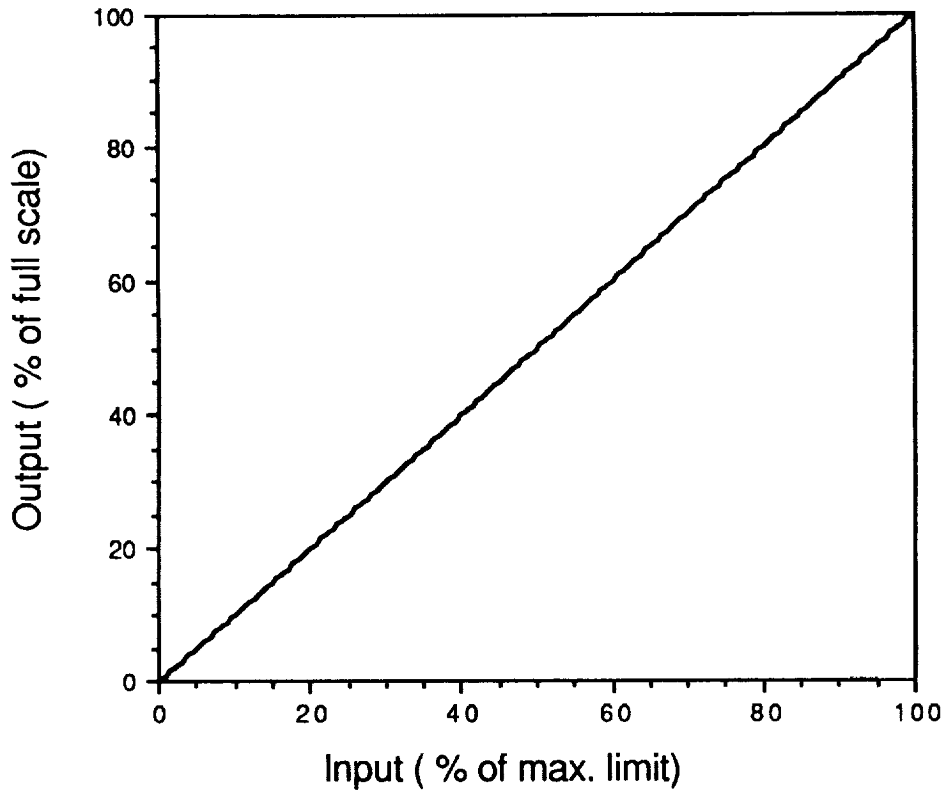



**Figure 3. - Linear Baseline Function**

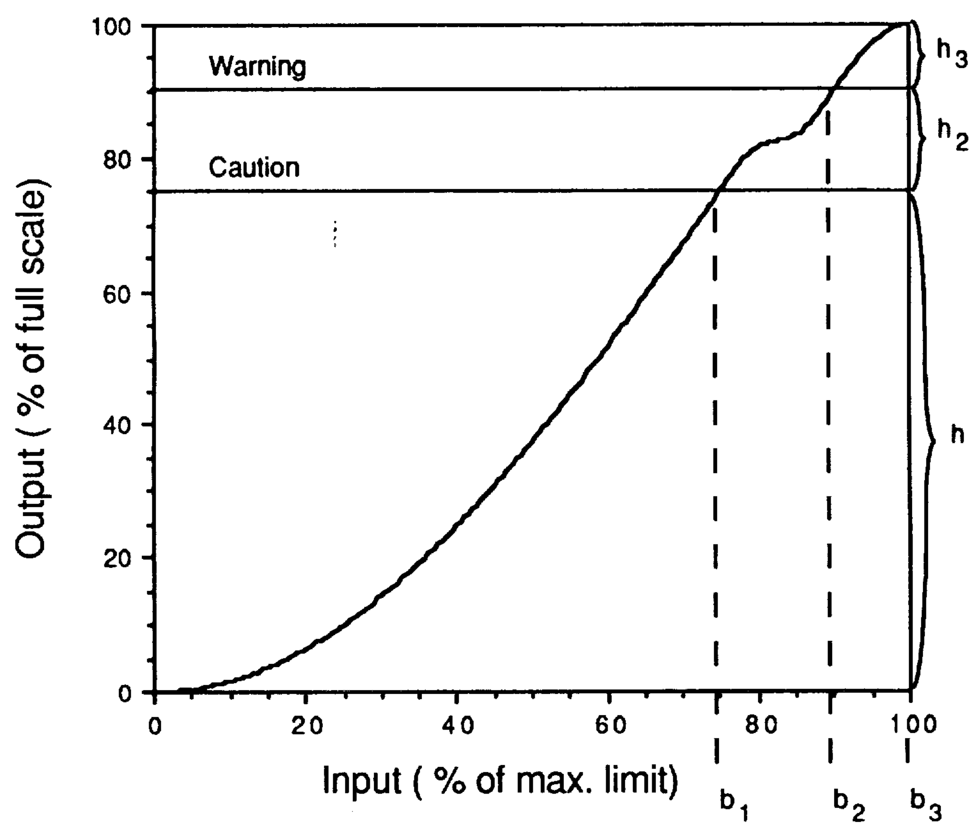



**Figure 4. - Fast Transition Function**

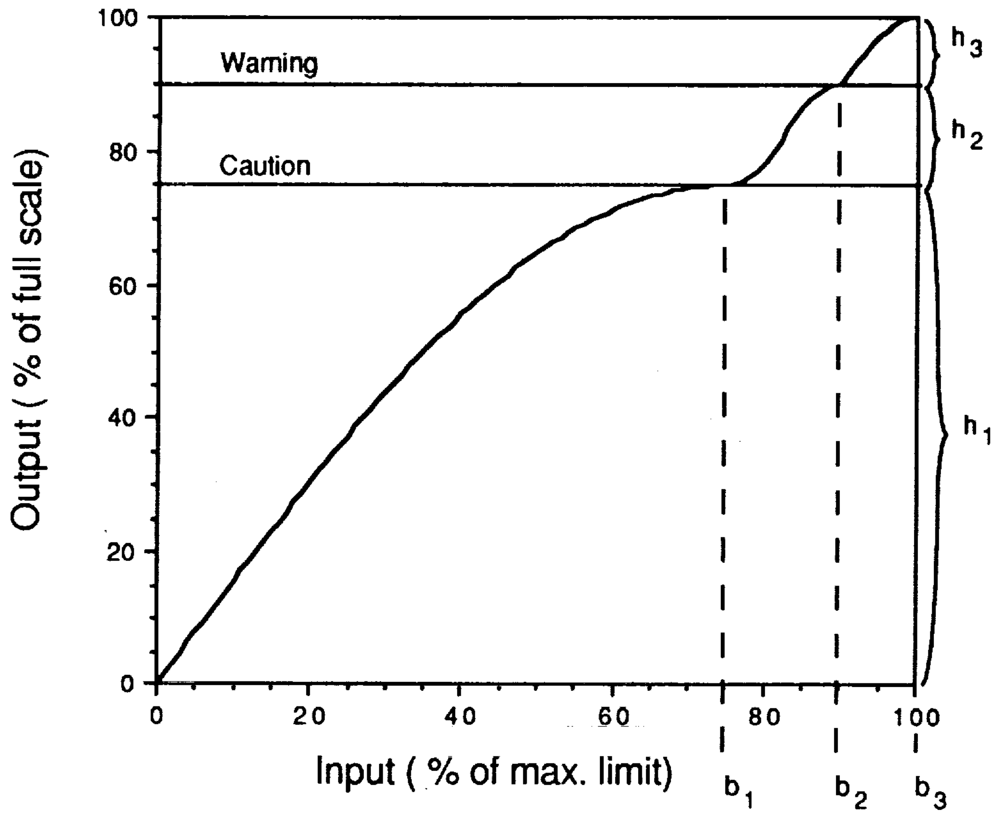



**Figure 5. - Slow Transition Function**

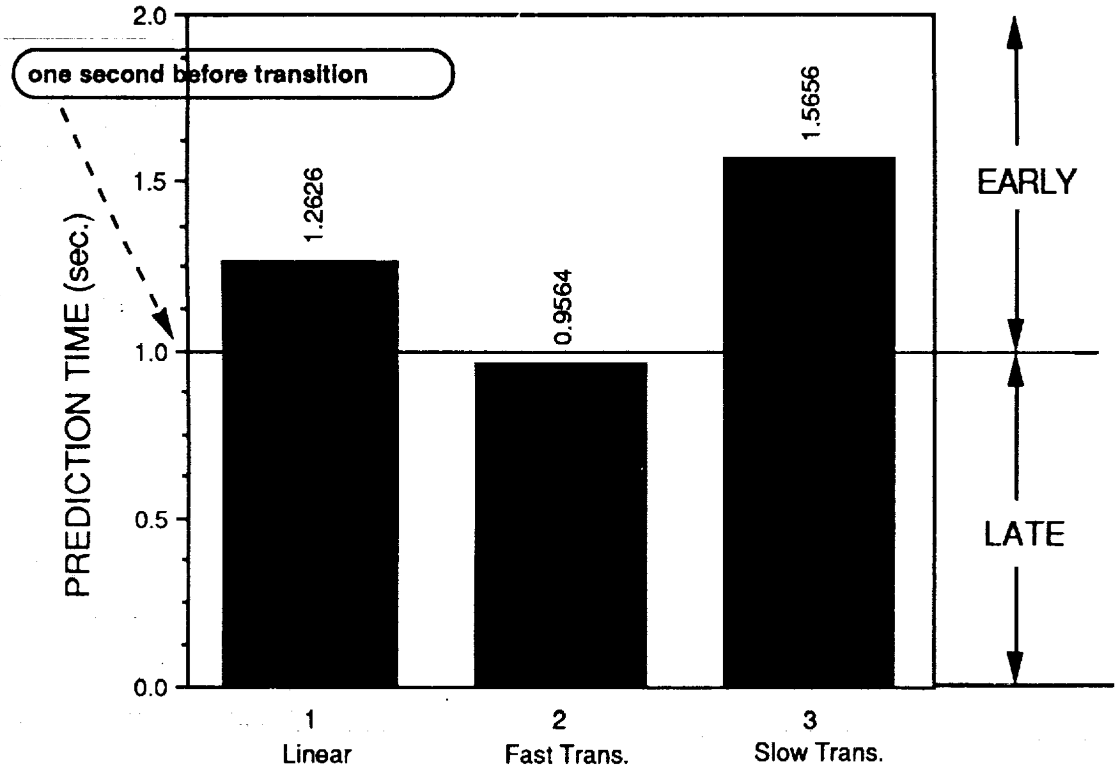



**Figure 6. - PREDICTION vs. SHAPER**
**mean response of 3 subjects**

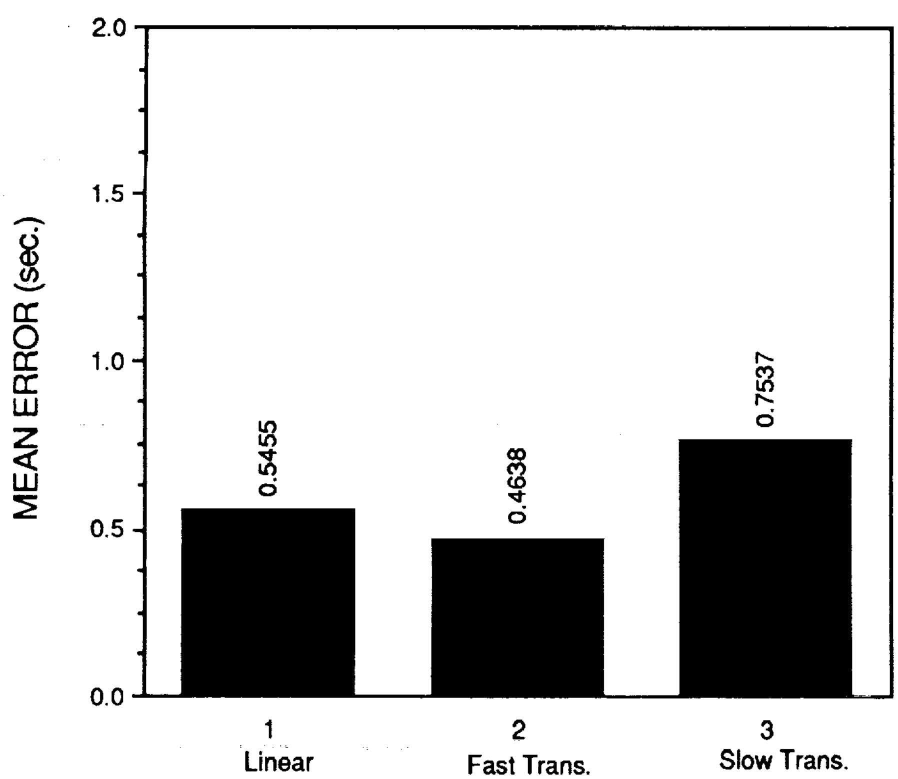



**Figure 7. - DETECTION vs. SHAPER**

NASA
National Aeronautics and Space Administration

# Report Documentation Page

| 1. Report No. | 2. Government Accession No. | 3. Recipient's Catalog No. |
|---|---|---|
| NASA TM-102737 | | |

| 4. Title and Subtitle | 5. Report Date |
|---|---|
| Effect of Shaping Sensor Data on Pilot Response | November 1990 |
| | 6. Performing Organization Code |
| 7. Author(s) | 8. Performing Organization Report No. |
| Roger M. Bailey | |
| | 10. Work Unit No. 505-67-01 |
| 9. Performing Organization Name and Address<br>NASA Langley Research Center<br>Hampton, VA 23665-5225 | 11. Contract or Grant No. |
| | 13. Type of Report and Period Covered<br>Technical Memorandum |
| 12. Sponsoring Agency Name and Address<br>National Aeronautics and Space Administration<br>Washington, DC 20546-0001 | 14. Sponsoring Agency Code |

15. Supplementary Notes

16. Abstract

The pilot of a modern jet aircraft is subjected to varying workloads while being responsible for multiple, ongoing tasks. The ability to associate the pilot's responses with the task/situation, by modifying the way information is presented relative to the task, could provide a means of reducing workload. To examine the feasibility of this concept, a real-time simulation study was undertaken to determine whether preprocessing of sensor data would affect pilot response. Results indicated that preprocessing could be an effective way to tailor the pilot's response to displayed data. In this study, the effects of three transformations or "shaping functions" were evaluated with respect to the pilot's ability to predict and detect out-of-tolerance conditions while monitoring an electronic engine display. In this experiment, two nonlinear transformations, one being the inverse of the other, were compared to a linear transformation. Results indicate that a nonlinear transformation that increases the rate-of-change of output relative to input tends to advance the prediction response and improve the detection response, while a nonlinear transformation that decreases the rate-of-change of output relative to input tends to lengthen the prediction response and make detection more difficult.

| 17. Key Words (Suggested by Author(s)) | 18. Distribution Statement |
|---|---|
| Information Display<br>Monitoring Systems | Unclassified-Unlimited<br><br>Subject Category 06 |

| 19. Security Classif. (of this report) | 20. Security Classif. (of this page) | 21. No. of pages | 22. Price |
|---|---|---|---|
| Unclassified | Unclassified | 18 | A03 |

NASA FORM 1626 OCT 86